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Engineering properties of granitic soils and rocks of Penang Island, Malaysia

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Abstract: The granitic rocks of Penang Island can be divided into two types, namely Type I (Sg. Ara) and Type II (Bt. Bendera), based on differences in age, mineralogy and texture of the rocks. These two types of granites and the soils derived from them exhibit soil mechanics, soil chemistry and rock mechanics properties which are rather different. Among the apparent differences: granitic soil I possesses high dispersion potential, while the dispersion potential for granitic soil II is low. Granite Type II shows strength/hardness which are higher compared to Granite Type I. Nevertheless, there are also some similarities in the properties mentioned between the two types of granites.

INTRODUCTION

Penang Island is one of the most highly developed regions in Malaysia. A recently completed research project on the engineering geology of Penang Island, Tan (1990), dealt with three aspects of studies, namely: engineering properties of the granitic soils, engineering properties of the granites, and slope stability. This paper summarises some results from this research project. It is reckoned that such information would be useful to the civil engineers in the planning and implementation of development projects on Penang Island.

GEOLOGY

The geology of Penang Island has been studied previously by various workers, notably Tjia (1971), Bignell and Snelling (1977), Ong (1982) and Amerizal G. Djafar (1983). Based on these previous studies and the author's recent field studies, it can be concluded that the granitic rocks of Penang Island can be divided into two types, namely:

Type I: Sg. Ara Type, and
Type II: Bt. Bendera Type.

This subdivision is based on differences in age, mineralogy and texture of the granites, whereby: Type I (Sg. Ara) is of late Carboniferous to early Permian in age, contains primary muscovite and is medium-grained, while Type II (Bt. Bendera) is of Triassic age, does not contain primary muscovite, and is coarse-grained. Incidentally, such an approach in the subdivision of the Penang Island granites has also been adopted by Chakraborty (1990) recently in his studies on the granites, in which he has named the two type of granites as the "Sg. Ara suite" and the "Bt. Bendera suite". In accordance with Chakraborty (1990), these two types of granites have originated from two different magmatic sources.

Figure 1 shows the distribution of the two types of granites in Penang Island. The Type I (Sg. Ara) granite is located in the southern region of the island, while Type II (Bt. Bendera) granite is located generally in the northern portion of the island, except for some around the Batu Maung area. The major fault striking roughly North-South and cutting the island into two as interpreted by Tjia (1971) from aerial photo lineaments is also shown in Figure 1. Recent field studies have encountered several field evidences (large quartz dyke/ridge striking ~ N-S around Paya Terumbung, fault planes exposed in quarry face around Tg. Bunga, etc.) substantiating the presence of this major fault.

Also indicated on Figure 1 are the localities where soil and rock samples have been collected. Rock samples taken from quarries comprise fresh rocks only, in the form of blocks measuring ~ 30 cm x 30 cm x 20 cm.

SOIL MECHANICS PROPERTIES

Soil mechanics properties studied include: specific gravity, water content, Atterberg limits and grain size distribution. The results are summarised as follows:

Figure 2 shows the histogram for the distribution of specific gravity values (Gs) for all soil samples. The Gs values range from 2.50–2.65, with 2.55–2.65 being the predominant values. This is in agreement with the Gs value for mineral quartz (Gs = 2.65) which form the major mineral in granitic soils, in particular the sandy soils. Comparing the Gs values for the two types of granitic soils (Type I

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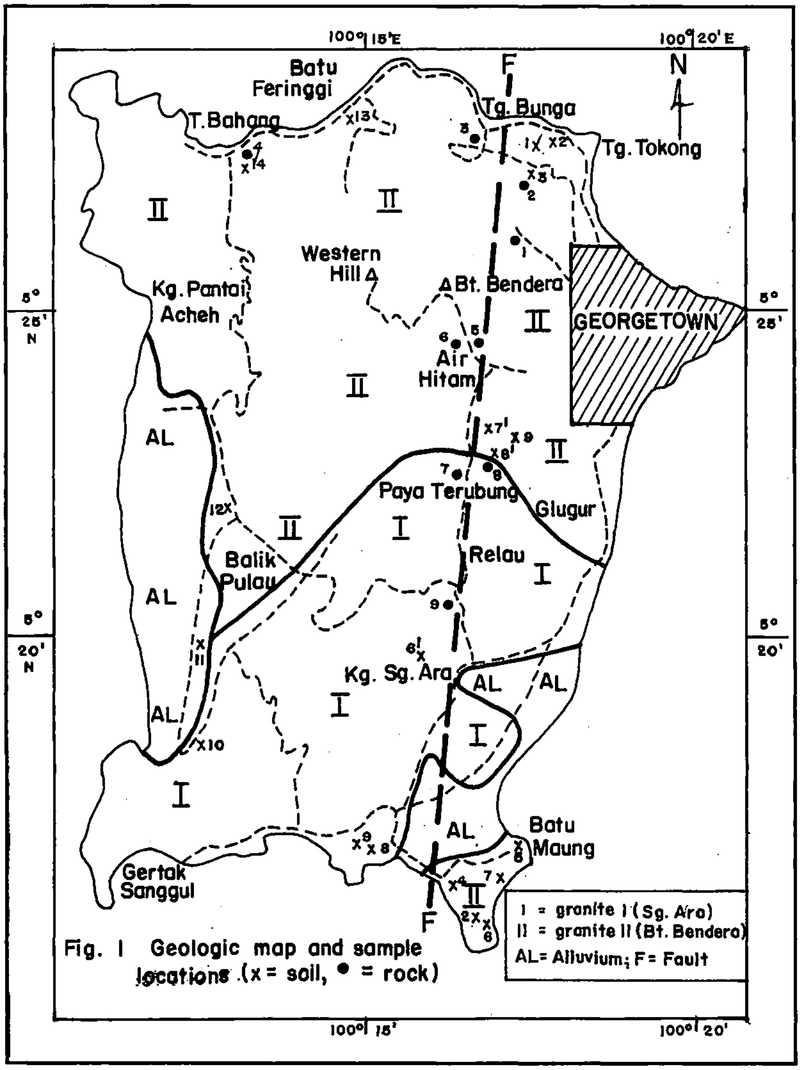

Figure 1. Geologic map and sample locations (x = soil, • = rock).

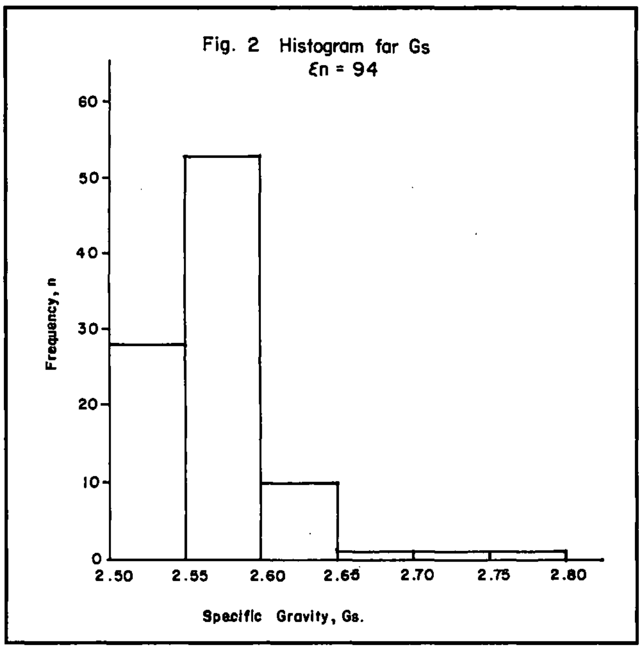

Figure 2. Histogram for Gs. Sn = 94.

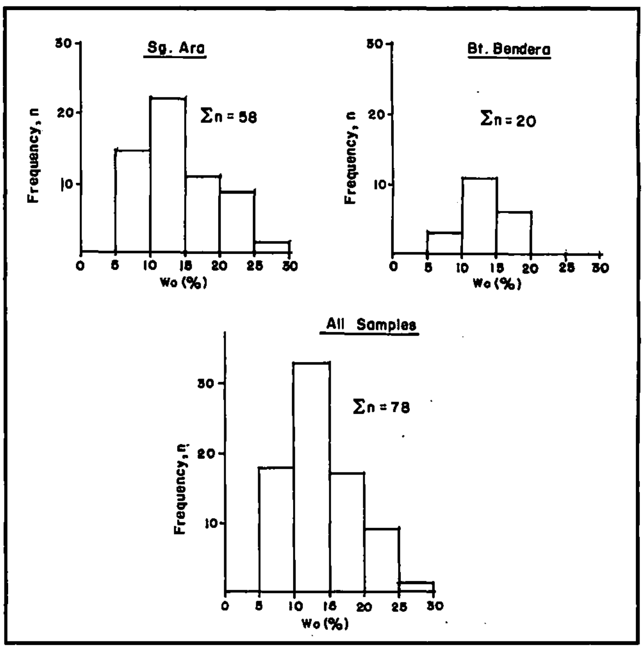

Figure 3. Histograms for Water Content.

and Type II), similar results are obtained as expected since the mineralogy of the two rocks are similar.

Figure 3 shows the histogram for water content (Wo) of all soil samples. The Wo values are low in general i.e. ranging from 5%–30%, with most values around 5%–20%. Again, there is not much difference in Wo of the two types of granitic soils.

Figure 4 and 5 show examples of results for Atterberg limits (Liquid Limit, L.L. and Plastic Limit, P.L.). Figure 4 shows the variation of L.L. and P.L. with depth, for example, as encountered in cut-slopes for housing projects or roads. It is clear from Figure 4 that the natural water content (Wo) is much lower than the L.L. and P.L. for the entire slope profile. This fact is true for granitic soils in general, as was also reported for other areas, e.g. Mun (1985). This would imply that residual granite soils are often in a "drier" or "hard" state, as such they make suitable construction materials. The variations in L.L. and P.L. with depth are also small, i.e. only ± 5% indicating little change in the fines (clay/silt) content along the profile.

Figure 5 shows the plasticity chart for Type II granite soils (Bt. Bendera). It shows that the Type II soils consist of ML mostly, with some CL, i.e. silts or clays of low plasticity. The L.L. ranges from 37%–50%. Similar plots are obtained for the Type I granite soils (Sg. Ara) indicating CL and ML soils also with L.L. ranging from 30%–50%.

Figure 6 shows examples on the variations of grain size with depth along the slope profile. In all the localities, sand is the major component of the granitic soils (51%–97%). The gravel content is rather low (0%–23%, mostly < 10%), while the silt and clay contents are low-moderate (3%–48%, mostly < 20%). Comparing Type I soil with Type II (Bt. Bendera) contains higher gravel content i.e. ~ 10%–20% compared to Type I (Sg. Ara, G < 10%). This difference is due to the Type II granite being coarsed-grained. The fines contents (silt/clay) for all localities also do not show much variations with depth. For Type II granite soils, the silt/clay contents are ~ 10%–20% mostly. For Type I granite soils the silt/clay contents are higher, i.e. ~ 10%–40%. This difference is attributed to the finer-grained texture of the Type I granite. From the grain size distribution curves, it is seen that the clay contents are very low, i.e. < 5% in general. As such, most of the fines are classified as ML (silts) as was observed previously in the plasticity charts.

SOIL PORE FLUIDS CHEMISTRY

Pore fluids of the various soil samples were extracted using the "Saturation Extract" method incorporating vacuum suction, Geotechnical Research Centre Manual (1985), McGill University, Montreal, Canada. The chemical compositions of the pore fluids were then determined, and include the following: pH, conductivity, cations concentration (Na^+, K^+, Ca^{2+}, Mg^{2+}) and anions concentrations (Cl^-, SO_4^{2-}). The concentrations of CO_3^{2-} and HCO_3^- were nil for all samples analysed.

From Figure 7, it is observed that the pH ranges from 5.06–7.80, with most values < 7, i.e. slightly acidic. Type II granite soils show slightly lower pH values (5.06–7.45) compared to Type I (6.20–7.80). Nonetheless, there is much overlapping in the pH values of the two types of soils, and most values fall between 6.0–7.0. The acidity of pore fluids of granitic soils has been reported previously by other workers, e.g. Todo and Pauzi (1989). Among others, the acidity of the pore fluids can be attributed to the presence of secondary iron oxides in the granitic soils resulting from weathering processes.

Conductivity represents the total cations concentrations in the pore fluids. The data obtained shows the wide range of conductivity values, from 24.2–235 u $S.cm^{-1}$. This means that some samples contain low cations concentrations, while others contain high cations concentrations. Comparing the two soil types reveal that Type I soils (56.6–235 u $S.cm^{-1}$).

Values for Na^+ concentrations range from 3.14–31.0 ppm, i.e. quite high when compared to other cations. Values for K^+ range from 0.38–8.00 ppm, i.e. rather low. There are no significant differences between the two types of soils studied.

The Ca^{2+} concentrations range from 1.23–15.0 ppm. In general, Type I soils show lower Ca^{2+} values than Type II soils. The values for Mg^{2+} concentrations are the lowest of all the cations analysed — values range from 0.015–2.07 ppm, with most values ~ 1 ppm.

In addition to the plots for individual cations, a plot showing the ratio of monovalent cations (Na^+ + K^+) versus divalent cations (Ca^{2+} + Mg^{2+}) was also made. The result shows the wide range of values from 0.8–9.5. It is observed also that Type I (Sg. Ara) soils show higher values (4–9.5) compared to Type II (Bt. Bendera) soils (1–2). Based on the difference in this ratio value, high ratio values (> 2) imply high dispersion potentials, Mitchell (1976). As such, based on this criterion, the Type I soils are interpreted to have high dispersion potentials while the Type II soils have low dispersivity.

In general, the order of abundance is as follows: $Na^+ >> Ca^{2+} > K^+ > Mg^{2+}$.

The anions Cl^- and SO_4^{2-} both show low concentrations. No apparent difference was noted for the two soil types.

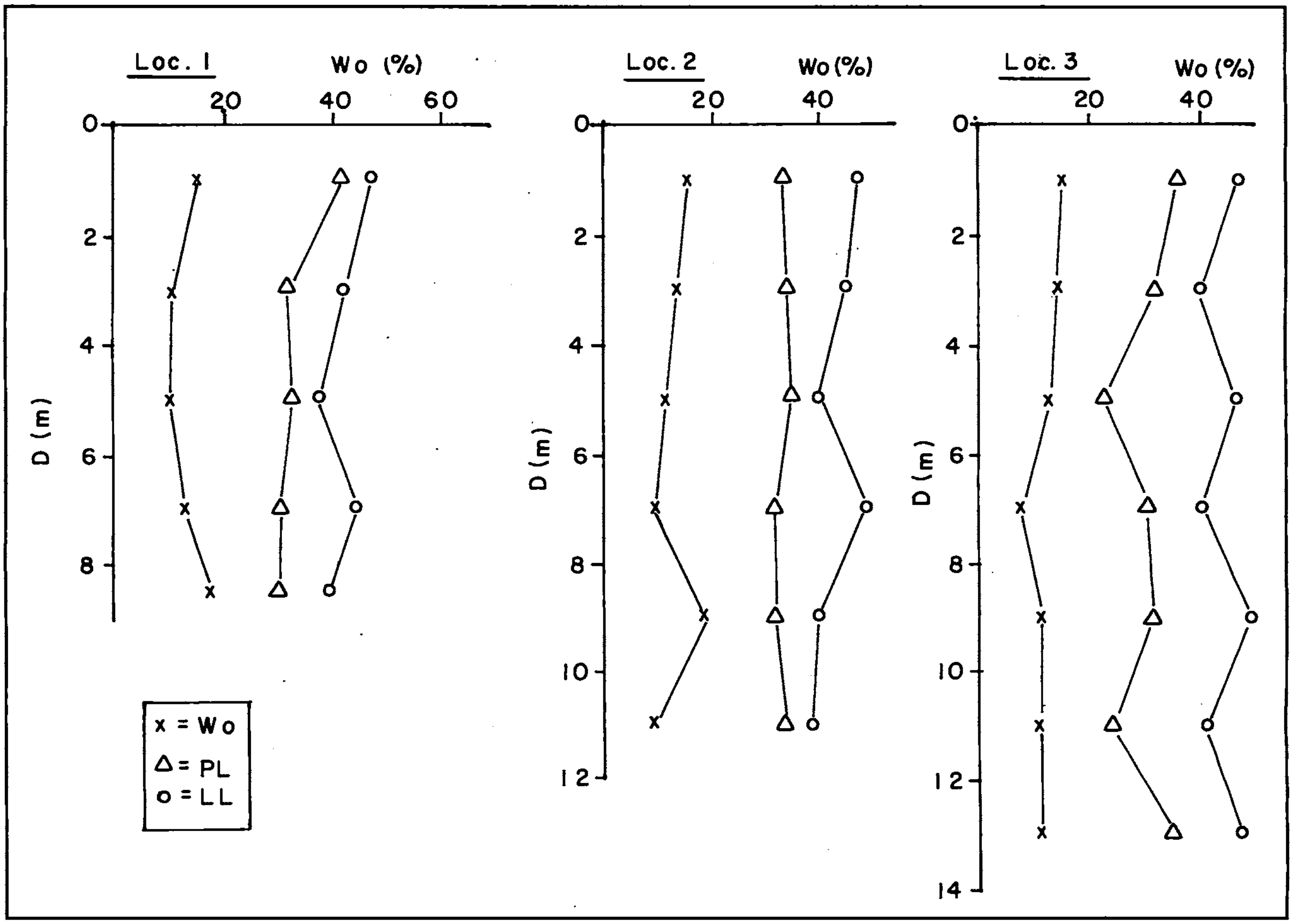

Figure 4. Water Content (Wo) vs Depth (D).

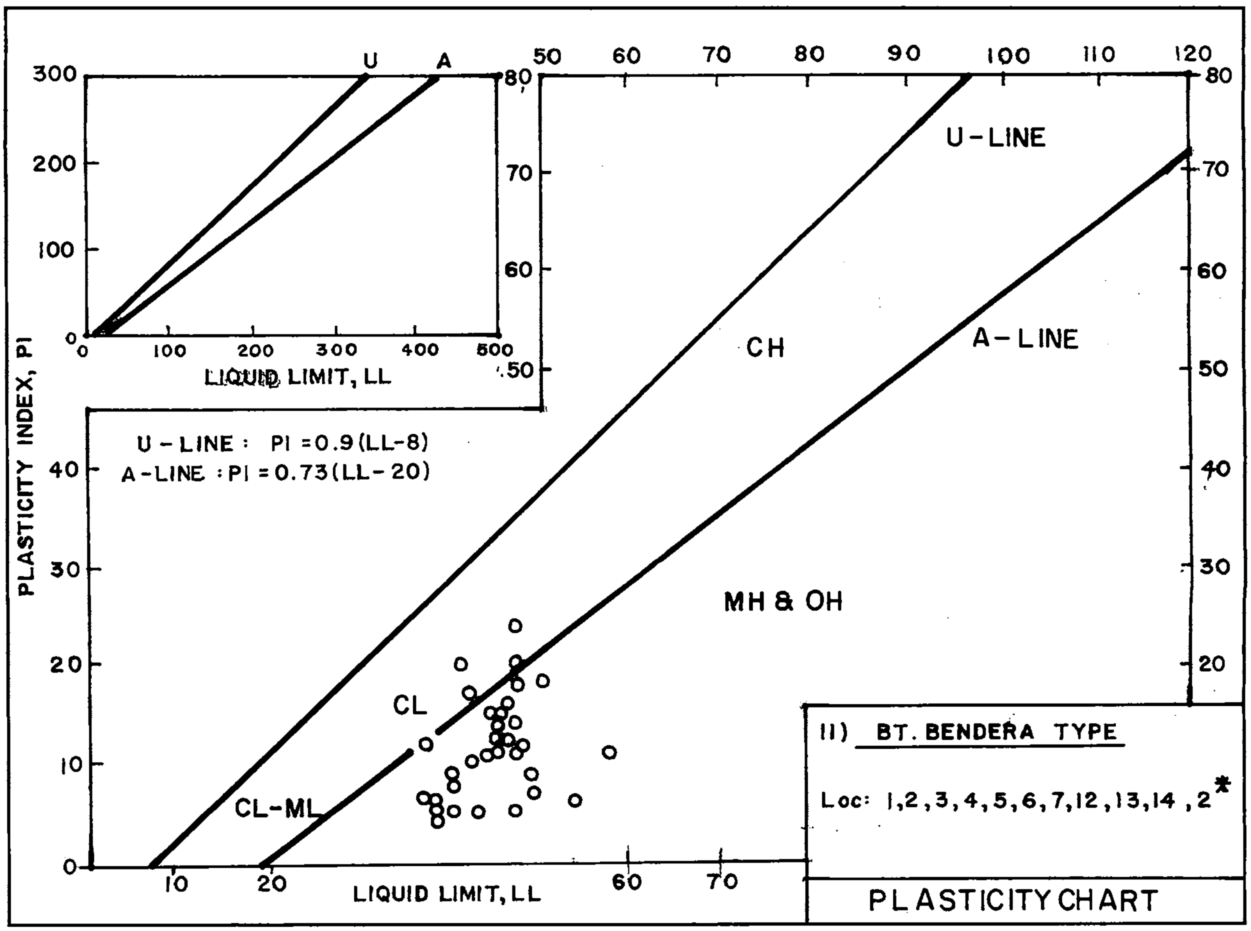

Figure 5. Atterberg limits.

ROCK MECHANICS PROPERTIES

The rock mechanics properties examined include: dry density, shore hardness, point load index, Brazilian tensile strength and uniaxial compressive strength (BS 1377, 1975; ISRM, 1978, 1979a, 1979b; U.S. Dept. of the Army, 1970). Only fresh rock samples (Grade I) were tested. Examples of test results are shown in Figure 8.

The values for dry densities of the granites obtained range from 2.56–2.63 g/cm^3, i.e. quite a narrow range. These values are rather high and consistent with the fresh rocks tested. The two types of granites give similar results.

Shore hardness (Sh) ranges from 76–100, i.e. rather high (fresh granite). Type I granite (76–97) shows slightly lower values than Type II granite (88–100). If we ignore the single value of Sh = 97 for Type I granite, then the range of values for Type I granite is 76–87, i.e. all much lower then Type II granite.

Range for point load index, Is (50), is between 2.1–11.8, i.e. values from low-high. In general, Type II granite shows slightly higher values than Type I, i.e. 3.7–11.8 compared to 2.1–9.2.

Uniaxial compressive strength (σc) ranges from 42.14–158.34 MPa, i.e. some values being rather high. It is obvious that Type II granite (47.33–158.34 MPa) shows much higher values than Type I granite (42.14–88.50 MPa).

From the test results obtained above, it can be concluded that the Type II granite (Bt. Bendera) shows strengths/hardness which are much higher than Type I granite (Sg. Ara). This apparent difference is possibly due to the differences in texture (grain size) and slight difference in mineralogical composition of the two types of granites. In the study on rock mechanics properties, only fresh rock samples are taken and tested to void variations due to differences in weathering grades of the rock samples. In any case, in the quarry and construction industries, usually only fresh rocks are utilised.

In addition to the determination of specific rock mechanics parameters as discussed above, several correlations between the parameters mentioned were attempted. Examples of these correlations are shown in Figure 9 and Figure 10. The following correlations can be derived.

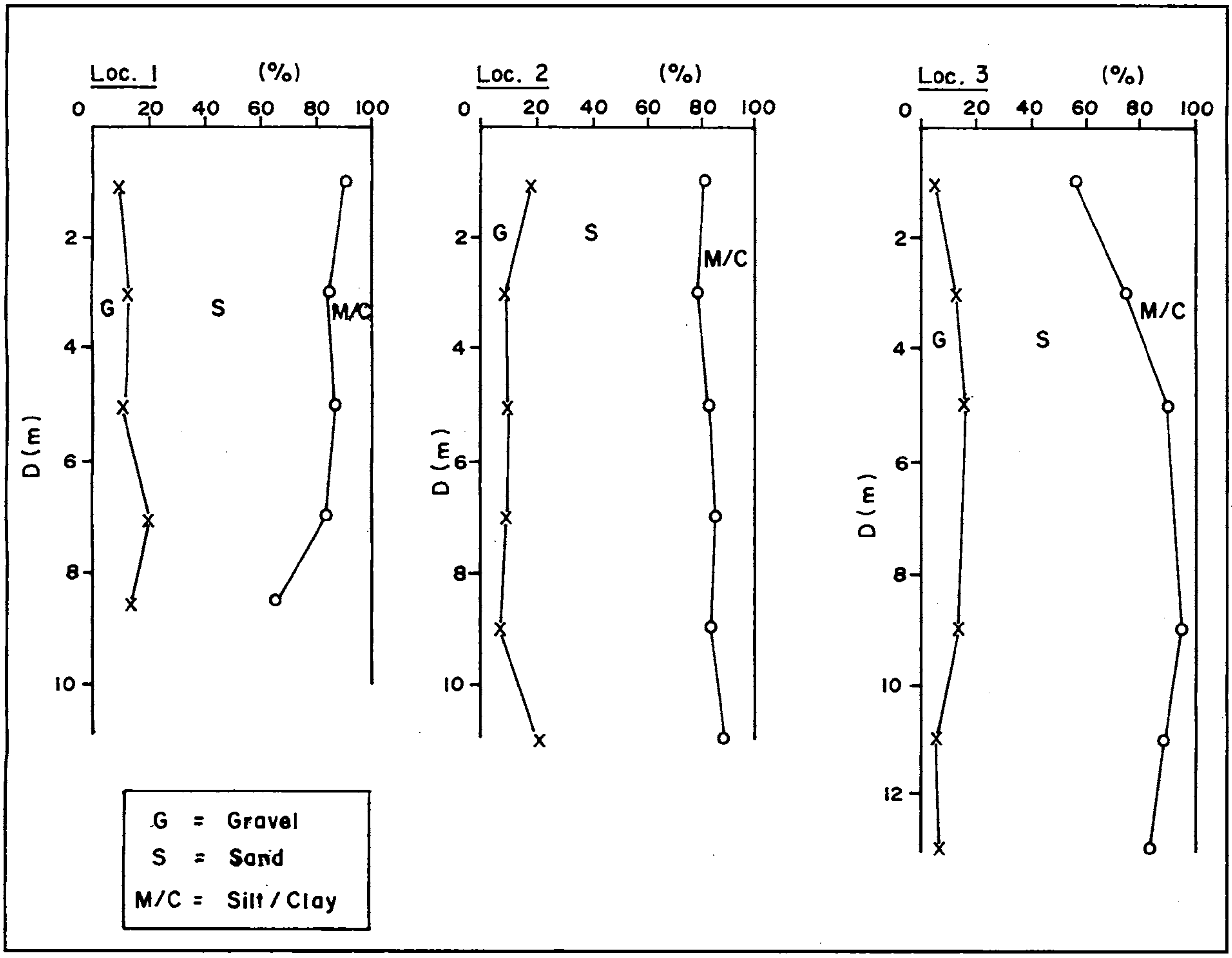

Figure 6. Grain Size vs Depth (D).

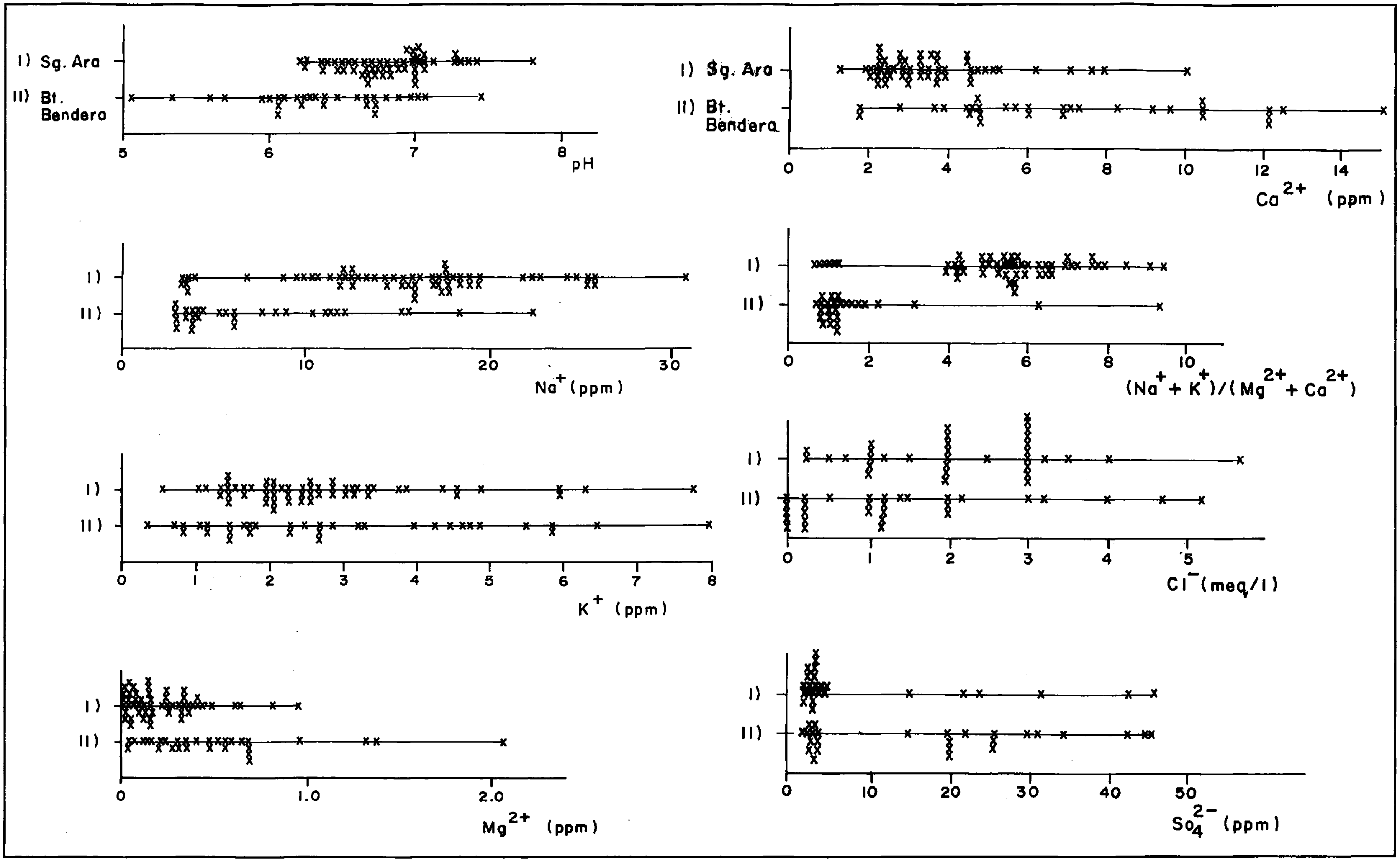

Figure 7. Soil Chemistry.

i) σc = 11.2 σt (upper bound)
ii) σc = 5.9 σt (lower bound)
i.e. σc = (6–11) σt
iii) σc = 17.3 Is (50) (upper bound)
iv) σc = 6.9 Is (50) (lower bound)
i.e. σc = (7–17) Is (50)

These correlations incorporate all the data obtained from this study, and do not differentiate between the two types of granites. Previous workers have presented such correlations before, e.g. ISRM (1985) proposes σc = 24 Is (50) based on various types of rocks including sedimentary rocks, etc.; and as a rough guide $\sigma c \sim 10\sigma t$ is widely accepted.

CONCLUSIONS

From the results of this study, the following concluding remarks can be made:

i) the granitic rocks of Penang Island can be subdivided into two types, namely Type I (Sg. Ara) and Type II (Bt. Bendera). This subdivision is based on differences in age, mineralogy and texture of the rocks.
ii) the specific gravity of the granitic soils ranges from 2.50–2.65, consistent with the mineralogy.
iii) the natural water content of the granitic soils is low, and much lower than the Atterberg limits.
iv) the fines fraction of the Penang Island granite soils can be classified as ML and CL, i.e. silt or clay of low plasticity.
v) in general, sand is the dominant component of granitic soils (51%–97%), as such granitic soils are always sandy in nature.
vi) pH of the pore fluids of granitic soils ranges from 5.06–7.80, i.e. acidic. The acidity is believed to be caused by the presence of secondary iron oxides.
vii) in general, the order of abundance of cations in the pore fluids is: $Na^+ >> Ca^{2+} > K^+ > Mg^{2+}$

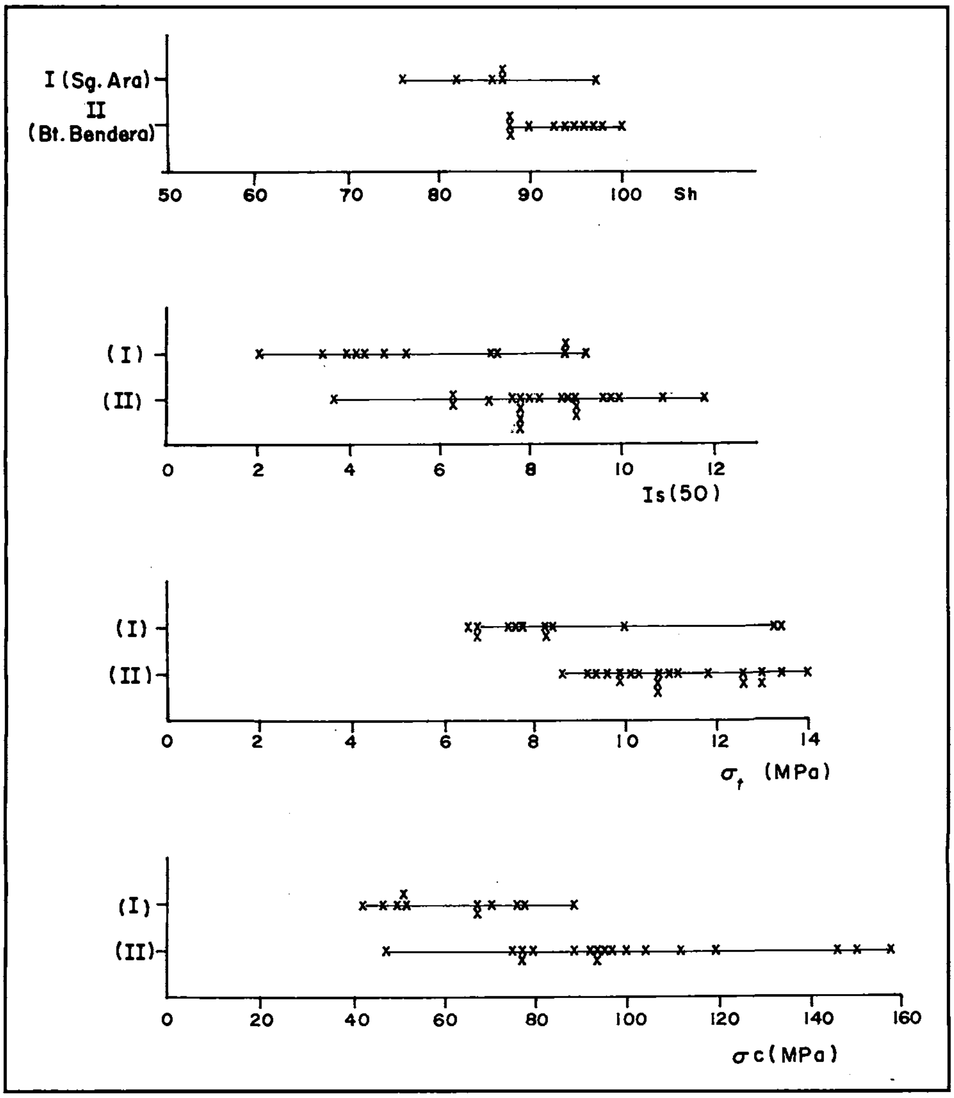

Figure 8. Rock mechanics properties.

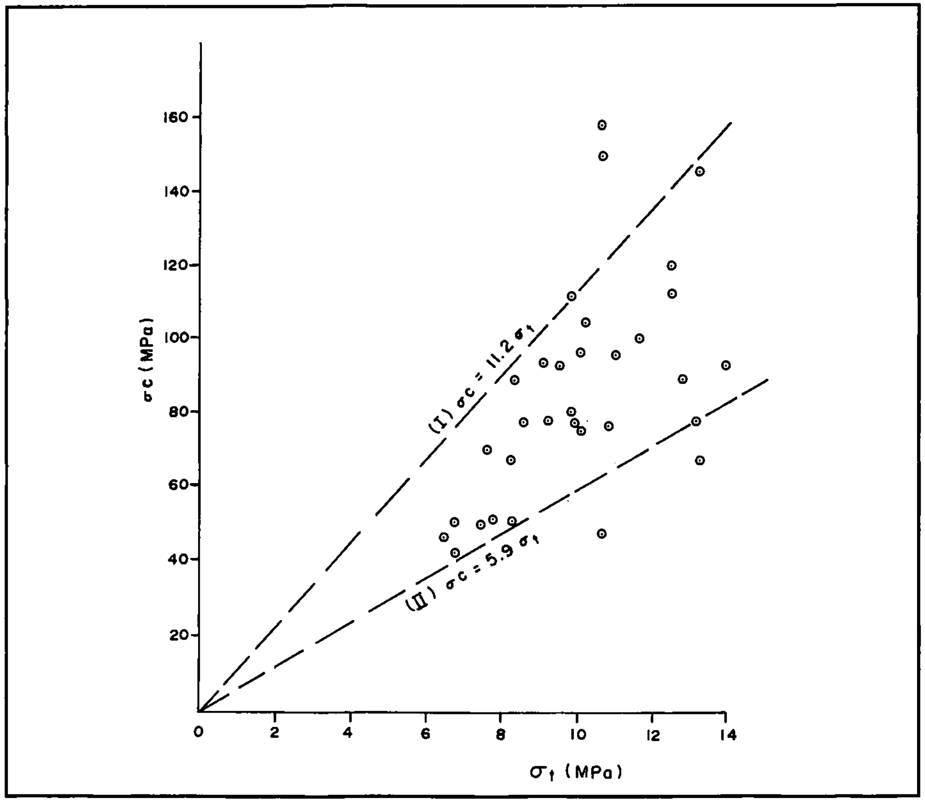

Figure 9. sc vs st.

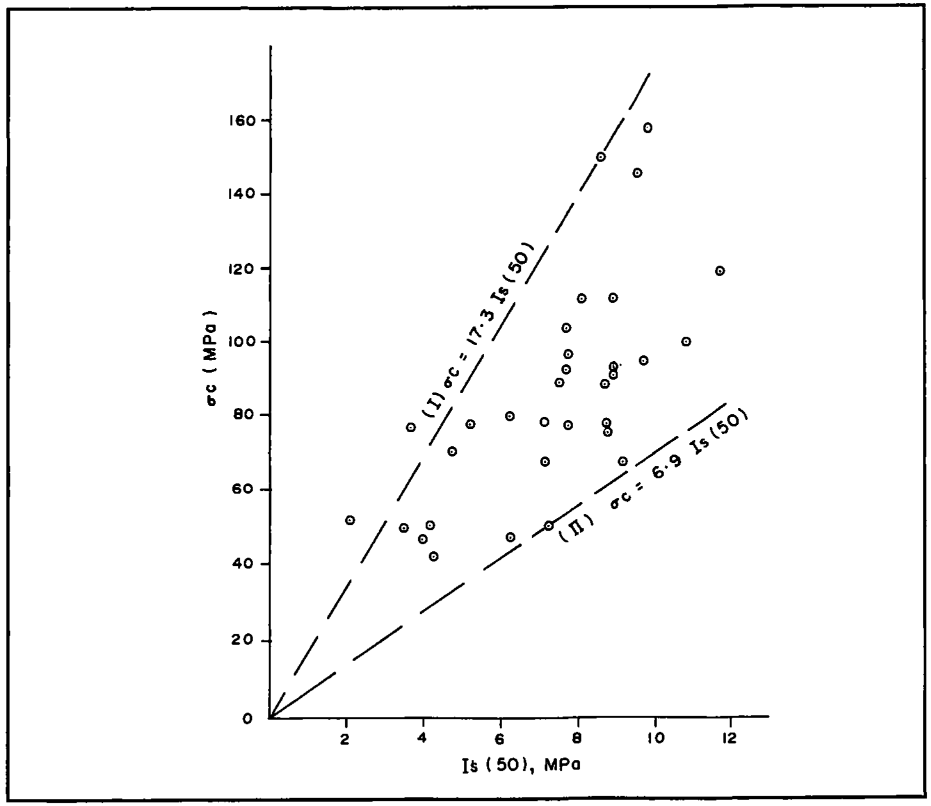

Figure 10. sc vs Is (50).

viii) based on the ratio of monovalent cations ($Na^+ + K^+$): divalent cations ($Ca^{2+} + Mg^{2+}$), Type I granite soils (Sg. Ara) is said to possess high dispersion potential, while Type II granite soils (Bt. Bendera) is of low dispersivity.

ix) as a whole, the rock mechanics parameters for both types of granites of Penang Island are high (this is in view of the fact that only fresh rock samples were tested).

x) Type II granite shows higher strengths/ hardness as compared to Type I granite. This is caused by differences in texture/grain size, and possibly also some slight differences in mineralogy.

xi) Positive correlations were obtained between uniaxial compressive strength, Brazilian tensile strength and the point load index. However, the correlation between strength parameters and Shore hardness, is not so good.

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REFERENCES

AMERIZAL G. DJAFAR, 1983. *Petrology and geochemistry of the granite rocks of Penang Island.* Unpubl. B.Sc. Thesis, Univ. Malaya, 51p.

BIGNELL, J.D. AND SNELLING N.J., 1977. Geochronology of Malayan granites. *Overseas Geology and Mineral Resources,* 47, 111p.

BS 1377, 1975. *Methods of test for soils for civil engineering purposes.* British Standards Institution, London.

CHAKRABORTY, K.R., 1990. Granitic rocks of Penang Island: Minor and trace element variation patterns and implications. *Annual Geological Conference '90, Geological Society of Malaysia, Ipoh, 7–8 May '90* (Abstract).

GEOTECHNICAL RESEARCH CENTRE (GRC) MANUAL, (1985) *Laboratory Manual,* McGill Univ., Montreal Canada.

ISRM, 1978. Suggested methods for determining tensile strength of rock materials. *Int. J. Rock Mech. Min. Sci.,* 15, 99–103.

ISRM, 1979a. Suggested methods for determining the uniaxial compressive strength and deformability of rock materials. *Int. J. Rock Mech. Min. Sci.,* 16, 135–140.

ISRM, 1979b. Suggested methods for determining point load strength. *Int. J. Rock Mech. Min. Sci.,* 22(2), 51–60.

MITCHELL, J.K., 1976. *Fundamentals of Soil Behaviour.* John Wiley & Sons, Inc., 422p.

MUN, K.P., 1985. Sampling and testing of residual soils in Malaysia. *In*: Brand, E.W. and Phillipson, H.B. (Eds.), *Sampling and testing of residual soils — a review of international practice,* 109–120.

ONG, W.S., 1982. Geology of Penang Island (sheet 28). *Geol. Survey Annual Report 1980,* 178–185.

TAN, B.K., 1990. *Kajian ciri tanah dan batuan serta kestabilan cerun di kawasan perbandaran Pulau Pinang.* (Studies on the characteristics of soils and rocks and slope stability in urban areas of Penang Island). Final Report, Research Project Code 81/87, July 1990, 86p, UKM.

TJIA, H.D., 1971. Lineament pattern on Penang Island, West Malaysia. *J. Trop. Geography,* 32, 56–61.

TODO, H. AND PAUSE, M.M., 1989. Geotechnical engineering properties of residual soils originated from granite in Malaysia and Singapore. *Proc. Int. Conf. on Engineering Geology In Tropical Terrains, Bangi, 26–29 Jun 89,* 160–169.

U.S. DEPT. OF THE ARMY, 1970. Laboratory soils testing. *Engineer Manual EM 1110-2-1906,* 30 Nov. 1970.

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